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Micro gas turbine cogeneration system with latent heat storage at the University: Part II: Part load and thermal priority mode

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HIGHLIGHTS

- Proper use of latent heat storage system saves energy and reduces exhaust emissions.
- Cogeneration with latent heat storage was demonstrated under service conditions.
- Irregular charge of latent heat storage system was discussed at a part load mode.
- Highly sophisticated system design is necessary for extending the system.

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ABSTRACT

A good cogeneration system should have high efficiency and good coordination. A micro gas turbine cogeneration system with latent heat storage was demonstrated at the University. Since there had been no cogeneration system with the latent heat storage under service condition, this system was the first demonstration and its characteristic was very important. The proper use of the latent heat storage system will save energy economically, store high energy density, reduce exhaust emissions, and save operational costs. A heat exchanger and an economizer were located in parallel downstream of a bypass dumper for exhaust gas. The latent heat storage tank was located downstream of the economizer. The bypass dumper released exhaust gas when the boiler water in the heat exchanger exceeded 90 °C. It is very important to use the heat supply of hot water as much as possible. At the University, the winter term heat demand from 6 pm to 7 pm was somewhat less than that from 8 am to 6 pm in 2010. We conducted a part-load operation from 6 pm to 7 pm to observe how it would respond to the heat demand. The heat supply from the cogeneration system during this time period was controllable with the heat storage. The heat supply from the system at the lowest power setting was larger than the heat demand, and thus was uncontrollable without heat storage.

In Part I [1], a fixed operating schedule of the system was planned and demonstrated at the University. Total 407 charge/discharge cycles of the latent heat storage were repeated. The energy flow test of the system shows the importance of heat release source and total system design. In Part III [2], a temperature control schedule of the system was demonstrated in winter morning using a new programmable logic controller (PLC). If the more larger latent heat storage system will be developed in the future, it will be expected greatly that the temperature of the classrooms are kept more comfortable with less energy consumptions and less CO_2 emission.

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1. Introduction

A cogeneration system efficiently supplies electric power and heat in a distributed energy system. Cogeneration systems were initially used mostly to compensate for an imperfect supply of grid power [3,4]. More recently, they have widely been used to help prevent global climate change and reduce energy costs. The prime movers utilized in such systems are gas turbines [3–6], gas engines [7,8], Stirling engines [9–11], and fuel cells [12]. The gas turbine is a good choice for larger distributed energy systems. Compared to reciprocating engines, gas turbines have higher specific power, are easy to soundproof and contain relatively few working parts [5]. Micro gas turbine cogeneration systems have become widespread over the past decade [13,14]. Many studies have analyzed the energy [15,16], exergy [3] and economy [17,18] of micro gas turbine cogeneration systems. However, these analyses were based on rated, nominal load specifications. Such limited field tests may obscure the actual efficiency and performance of such systems [5].

Prime movers can be operated at rated or part load. The supply of electric power and the heat of the prime movers must not exceed the demand, otherwise the excess supply must be stored somewhere. In part-load operation, the controlled target is either the heat (thermal priority mode, heat load following mode) or the electric power (electric priority mode, electrical load following mode) [19–21]. Part-load gas turbines have some disadvantages compared to reciprocating engines and fuel cells. One is the efficiency of electricity generation. When the load decreases, the efficiency of electricity generation decreases in gas turbines but stays constant in fuel cells [22]. Harveya et al. [23] proposed power reduction by fuel flow or compressor recirculation and analyzed the efficiency map of 9–40 MW class of gas turbines. Kim et al. [24] proposed power control by fuel only, along with variable speed or a variable inlet guide vane, and analyzed the efficiency map. The other disadvantage comes from the regulation of clean exhaust gas of the prime movers. Gas turbines adopt low-NO_x, premixed-lean combustion at the rated load. A narrow operating range of premixed-lean combustion makes use of a staging combustor [25–27] between diffusion combustion at low load and premixed-lean combustion at high load, which in turn requires a switchable premix-diffusion combustor. However, such combustors do not function in reciprocating engines. Luigi et al. [28] tested the exhaust gas of a micro gas turbine operated at part load, and Pierluigi et al. [29] modeled and estimated the exhaust emissions of a micro gas turbine operated at part load.

From 2006 to 2010, the National Institute of Advanced Industrial Science and Technology (AIST) in Japan demonstrated a micro gas turbine cogeneration system with latent heat storage at the University. The latent heat storage system was an original design of AIST [30] and it used phase-change material (PCM) [31]. Latent heat storage systems are able to store heat for a long period of time with little heat loss. They utilize waste heat due to spatial and temporal mismatching when there is a difference between the time that electric power is generated and the time that heat is utilized. Overcoming this spatiotemporal mismatch in heat use and electricity utilization is the major challenge in distributed energy systems.

The latent heat storage system was a novel heat storage system, and it was demonstrated with a micro gas turbine cogeneration system at the University under service conditions. Expanding the latent heat storage system is greatly expected to save energy and initial and operational costs, and to reduce exhaust emissions. It is necessary to perform proper operation in the higher power cogeneration system with latent heat storage. Since there had been no cogeneration system with latent heat storage under service condition, this system was the first demonstration and its characteristic was very important. Proper use of the latent heat storage system will save not only energy but also initial and operational costs. In addition, the new storage system reduces exhaust emissions.

In Part I [1], the plan and energy flow test of the system was described. An operation schedule of the cogeneration system with latent heat storage was planned, and then the system was demonstrated at the University under service conditions. The latent heat storage system was charged during the daytime and discharged during the evening and next morning. Total 407 charge/discharge cycles of the latent heat storage system were repeated at the University. The latent heat storage system saved energy, but the total system efficiency was not so high. The energy flow test of the cogeneration system revealed the importance of heat exchanger and operational time for heat storage.

In Part II, a part load and thermal priority mode of the cogeneration system was described. An irregular charge case of the latent heat storage system was discussed. In normal situation, the latent heat storage system was expected to save energy and reduce exhaust emissions. Surplus heat of the cogeneration system made a gas turbine operated at a part load and thermal priority mode. In the specific system, when controlled to heat quantity of heat exchanger of the cogeneration system, the latent heat storage system failed because of low charging temperature of PCM. When maintaining high charging temperature of PCM, mechanical damage might occur to the gas turbine because of the switchable combustor design. These problems were not solved in the specific system, but will be solved in the highly sophisticated designed system with latent heat storage.

In Part III [2], a temperature control schedule of the system was described. Apart from a fixed operating schedule, temperature control schedule in winter morning was demonstrated at the University because it was expected to save energy, CO_2 emissions, and operational costs. The charge/discharge sequences of the latent heat storage system were interlocked with the operation of the micro gas turbine, and it was repeated completely using a new programmable logic controller (PLC). Temperature rise of the big lecture hall was controlled, and it was proportional to heat supply to header system of the building. Temperature rise will be improved if controlling start time of air-heater and heat output of the original boiler. A highly sophisticated system design that the more larger latent heat storage system heats the big lecture hall in winter morning will be expected to drastically improve the temperature of the classrooms being kept more comfortable with less energy consumptions and less CO_2 emission.

2. Latent heat storage

The exterior of the latent heat storage tank was made of SUS304 stainless steel and was 1.8 m high and 348 mm in diameter with 96 PCM capsules, each 1.6 m long and 28.6 mm outer diameter [1]. The heat storage tank was filled with hot water pumped from an economizer (heat exchanger) and was surrounded by thermal insulation. There were some valves controlling the flow of hot water.

The PCM is in a solid phase at low temperature, but when sufficient heat is applied it changes to a liquid phase. After heating is stopped, the sensible heat is first released in the liquid phase, causing the temperature to decrease, and then the PCM changes into an under-cooled liquid state. The heat storage system can sustain the PCM in this state for more than 8 h. Secondly, a nucleating agent (forming seed) is used to stop the under-cooling, and the material changes back into its solid phase. The latent heat of solidification increases the temperature to near melting point and then heat is released in the solid phase. The PCM used